Fabrication of High Q Microdisk Resonators using Thermal Nanoimprint Lithography

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Abstract: We demonstrate the fabrication of high Q microdisk resonators on an SOI platform using thermal nanoimprint lithography. The achieved Q factor is 60000 for 2µm radius disks. Arrays of 32 resonators show uniform spectral response.

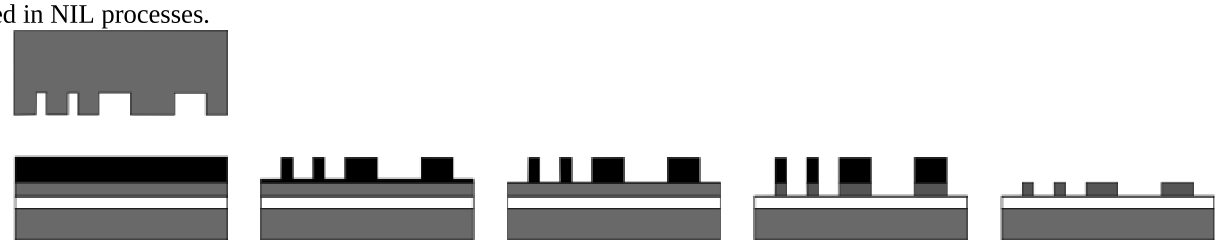
OCIS codes: (130.3120) Integrated Optics devices; (220.4241) Nanostructure fabrication

1. Introduction

Nanoimprint lithography (NIL) is gaining more and more interest in the applications where high resolution and relatively low cost are required. Nanophotonic circuit components are among the most promising application of the nanoimprint. Several authors reported the use of thermal or UV nanoimprint for the fabrication of optical integrated resonators on polymer[1] or SOI [2] respectively. The current paper aims at demonstrating the potential and benefits of using thermal nanoimprint lithography fabrication for high quality factor (Q) silicon micro-disk resonators. The major advantage of thermal imprint is that it allows using silicon molds. Being able to use the well mastered silicon processing technologies for the fabrication of the template is a major advantage. It allows a much better control of the feature shape and size that soft materials like PDMS and is much easier to be processed with high resolution than quartz templates. In this paper we demonstrate the possibility of fabricating high quality factor disk resonators using this technique [3].

2. Description of the process

The process flow is summarized in Figure 1.The imprinting processes was performed in an EVG®520HE imprint tool. The force applied by the piston is 40 kN, which is equivalent to a pressure of 12.7 bar over a 200mm wafer. The printing process is performed under vacuum (7×10^{-2} mbar), and a printing time set to 5 min. A Sumitomo NEB 22 resist film was spin coated on a SOI substrate. The glass transition temperature of this resist is about 80 °C and all the prints were performed at 130 °C. The 250nm deep silicon mold, printed using e-beam lithography and etched using a $Cl_2/HBr/O_2$ chemistry is covered with an anti-sticking layer of perfluoro-octyltrichlorosilane commonly used in NIL processes.



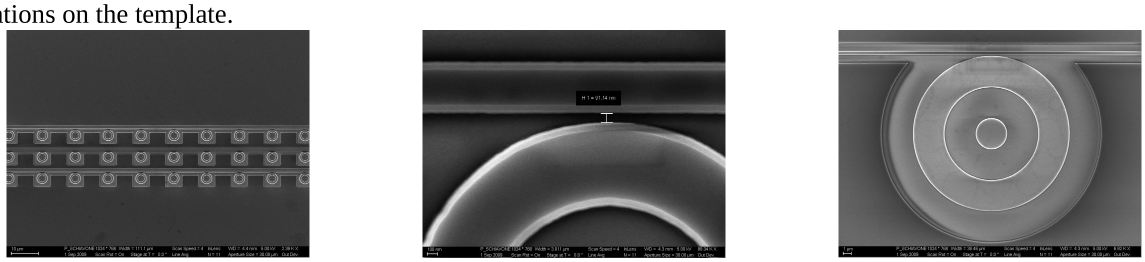
(a) (b) (c) (d (e)

Figure 1: Summary of the process flow. (a): imprint of the resist coated SOI wafer. (b) Imprinted resist layer on top of the SOI wafer; (c):etch of the residual resist thickness. (d): Etch of the silicon layer using the imprinted resist as a mask and the oxide layer as an etch stop.(e) Removal of the resist mask to get the final SOI device.

Residual resist layer has been etched using a $O_2/Cl_2/Ar$ plasma process in an Applied Materials IPC reactor. The used process was developed to achieve an improved anisotropy of the polymer etch step. This makes the process more robust to the dispersion in the residual thickness which is unavoidable when features of different densities are to be printed [4]. The transfer of resist patterns into silicon substrates was done with as a well-known $Cl_2/HBr/O_2$ chemistry, already used for industrial processes in the same reactor.

3. Results:

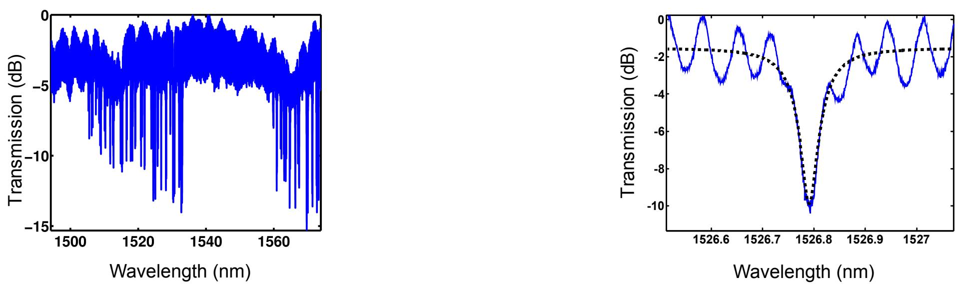
Examples of several devices fabricated on SOI after the full process are shown in Figure 2. The Si device layer thickness was 230nm. The improved residual layer etch step allows maintaining a good control of the gap between the resonator and the waveguide. Figure 2(a) shows an example of a 100nm gap. Narrower gaps down to 50nm could be resolved on the same sample. Various devices are imprinted at the same time such as the ones shown in Figure 2(a) and (c) Note that the mold is designed to be a “high level” type, to minimize the influence of the density variations on the template.



(a) (b) (c

Figure 2: SEM images of several devices fabricated on SOI after the full process. (a) series of 2μm disk resonators.(b) close up on the sub 100nm gap between the resonator and the waveguide; (c) 10μm disk resonator.

The measured optical response for an array of 32 resonators (2 μm radius microdisk) side coupled to a single waveguide is shown in Figure 3(a). The free spectral range (FSR) is observed to be 54.6 nm. The resonance peak of each resonator is slightly offset to enable interrogation with a single waveguide input. The higher order modes are suppressed using the microdonut structure. A detailed spectral shape of a single resonance peak is shown in Figure 3(b). The extracted unloaded quality factor is 60,000, which is in the same range as those of devices, directly fabricated by e-beam lithography. The resonance peaks of different microdisks show fairly uniform quality.



(a) (b)

Figure 3: Optical response of a series of 2μm microdisk resonator as shown in Figure 2(a). (a) full spectral response.(b) close-up on a resonance peak and the lorentzian lineshape fit shoowing unloaded Q ~ 60,000

4. Conclusion:

We demonstrated the successful use of thermal nanoimprint lithography for the fabrication of silicon micro-disk resonators. The fabricated devices show a quality factor as high as 60000 for miniature microdisks (radius 2μm) and arrays of up to 32 resonators show fairly uniform optical responses.. This cost-effective technology can be a path toward widespread of silicon photonic devices. Further work will allow comparing the performance of nanoimprinted devices to their e-beam printed counterparts. A good process control is a major issue for most of the silicon photonic components; it is expected to be improved using nanoimprint lithography. We are currently working to verify this hypothesis.

5. References

[1] Chao, C.-y. and Guo, L. J., "Polymer microring resonators fabricated by nanoimprint technique", J. Vac. Sci. Technol. B 20(6), 2862-2866 (2002).

[2] Plachetka, U., Koo, N., Wahlbrink, T., Bolten, J., Waldow, M., Plotzing, T., Forst, M. and Kurz, H., "Fabrication of Photonic Ring Resonator Device in Silicon Waveguide Technology Using Soft UV-Nanoimprint Lithography", IEEE Photonics Technology Letters 20(7), 490-492 (2008).

[3] Scheerlinck, S., Pedersen, R. H., Dumon, P., Bogaerts, W., Plachetka, U., Van Thourhout, D., Baets, R. and Kristensen, A., "Fabrication of nanophotonic circuit components by thermal nano imprint lithography", Proc. CLEO/QELS 2008. 1-2 (2008).

[4] Chaix, N., Gourgon, C., Perret, C., Landis, S. and Leveder, T., "Nanoimprint lithography processes on 200 mm Si wafer for optical application: Residual thickness etching anisotropy", J. Vac. Sci. Technol. B 25(6), 2346-2351 (2007).